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NRL Memorandum Report 1255

STANDARD EVALUATION PROCEDURES FOR EXPLOSION BULGE TESTING

(Weldments)

P. P. Puzak and W. S. Pellini

METALLURGY DIVISION

December 1961

U. S. NAVAL RESEARCH LABORATORY
Washington, D.C.

MEMORANDUM REPORT NO. 1255

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BY

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ABSTRACT

The Explosion Bulge Test was developed in 1949-1950 and has been used extensively to investigate the factors which determine the performance of weldments, particularly submarine structures and other large welded steel structures. The test was demonstrated to be a simple and reliable method for determining the performance characteristics of service type weldments and it represents the only feasible testing procedure by which the heat-affected zone of weldments can be fully evaluated.

In addition to continued use of explosion-loading tests for research investigations conducted by the U. S. Naval Research Laboratory, explosion-bulge test facilities have now been established at several Naval activities and other locations may be authorized in the future. In order to insure that tests conducted at different (or new) locations will have a common meaning, it has become necessary to prepare a standard evaluation procedure. The procedural details given herein are recommended for consideration by cognizant BUSHIPS agencies for specification as a standard for explosion testing of weldments of HY-80, STS, and alloy steels of similar properties.

PROBLEM STATUS

This is a final report of one phase of HY-80 weldment studies; work on this problem is continuing.

AUTHORIZATION

NRL PROBLEM NUMBER MO3-01
BUREAU PROJECT NUMBER - SR 007-01-01

STANDARD EVALUATION PROCEDURES FOR EXPLOSION BULGE TESTING (Weldments)

A. INTRODUCTION

This document covers standard evaluation procedures for explosion bulge testing of weldments of HY-80, STS, and alloy steels of similar properties.

In the interests of standardization, all activities conducting such tests for the Navy shall conform to the procedures specified herein.

B. EXPLOSION TEST SPECIMENS (Weldments)

1. Number of Samples - For relatively new or previously untested materials or welding processes, satisfactory performance in the bulge test shall be based upon results obtained for a minimum of five to six samples, or more, as determined by the Bureau of Ships. For previously tested materials or welding processes which failed to meet acceptability, a minimum of five to six samples also are required.

2. Conventional Bulge Test Samples - Butt welds, prepared as shown in Fig. 1, may be fabricated by using any plate edge preparation, material and welding procedure for which an evaluation is desired. However, similar welding conditions and identical materials shall be used for these samples such that each is representative of the same variables being evaluated. A record shall be kept of all fabricating details. On the side of the weldment which will contact the die, each end of the weld crown shall be ground flush with the plate surface for the distance shown in Fig. 1, to allow proper seating of the sample on the die hold-down regions. The weld reinforcement of the remaining weld between these two end zones shall remain intact -- and shall not be ground or removed.

3. Crack-Starter Modified Bulge-Test Samples - Two of the samples prepared as specified above, shall be modified by the addition of brittle Murex Hardex N crack-starter weld beads as shown in Fig. 1 (b) These electrodes may be obtained from:

Metal & Thermit Corporation
Rahway, New Jersey
Attention: Mr C. F. Delbridge
Telephone: FUlton 1-3000

A 3/16 inch diameter electrode shall be used - at 180 to 200 amperes, a medium arc length, and at a travel speed which will result in a moderately high-crowned bead. An oscillating or weaving motion is unnecessary, since this electrode naturally deposits a bead having a width of from 1/2 to 5/8 inches. The deposit shall be placed directly on the weld joint, parallel to the axis of the weld. In the case of a wide weld joint, such as in plates of 1-1/2 inch thickness or more, two Hardex N beads shall be placed as shown in Fig. 1 (b), so that the outside edges of the crack-starter welds shall be a nominal 1/16 inch or less from the edges of the weld at the toe areas. If the crack-starter weld overlaps the edge of the underlying weld joint by no more than 1/16 inch at any point, this shall not be a cause for rejection of the sample. The crack-starter welds shall be approximately 2-1/2 inches long, shall be placed midway between the extremities of the weld joint and shall be applied in a manner such that welding proceeds from the ends of the crack-starter welds and terminates in the center. The thickness of the crack-starter bead at the center crater position should be approximately equal to the thickness at other locations - but any deficiency observed after cleaning the weld can be corrected by adding more metal to the crater depression.

Final preparation of the crack-starter modified samples shall consist of notching the deposited hard-facing metal at the center as shown in Fig. 1 (b). This may be done with a thin 1 inch diameter abrasive disk (such as a Ticonium separation disk) on a flexible shaft machine. Notches shall be cut normal to the surface of the specimen and across the full width of the crack-starter bead - to a depth such that at least 0.070" "remains" between the bottom of the notch and the surface of the underlying plate or weld. This dimension is arbitrarily standardized and is not critical - but, under no condition shall the notch be cut into either the joint bead or the plate.

4. Explosion-Test Conditions and Materials - Weldments prepared as specified in (2) and (3), above, are ready for refrigeration to the specified testing temperature. The test temperature shall be 0°F for all specimens. Experience has shown a mechanical-refrigeration type cold box with a propeller type fan air circulator to be superior to the dry ice type equipped with a squirrel-cage centrifugal type circulator. However, any refrigeration equipment capable of obtaining and maintaining the test temperature in the larger samples is acceptable. It will be necessary to refrigerate to a level below the testing temperature in order to compensate for heat gain during handling - to assure that

testing temperature is not being significantly exceeded. Rate of heat gain is a function of plate thickness, ambient temperature, and the time lapse between withdrawal and firing. The degree of under-cooling employed should be checked by making use of "control" plates until experience has been well established.

Originally, the standard dies, Fig. 2, were cut from scrap 3" thick STS armor steel. However, equally suitable dies can be made from cast alloy steels having equivalent properties. At least two or more dies, stacked on top of each other, are required to provide a die-cavity deep enough to permit the development of a full hemisphere bulge. Corners of the larger die may be cut off on a 17 inch radius, if desired - to facilitate handling.

Table I specifies the preliminary charge-weight and stand-off distance for different thicknesses of test plates. These may be changed where found necessary as described below in paragraph 6. Charge weights are based on use of pentolite explosive. This explosive may be obtained, molded in 1-pound, 4-pound and 7-pound wafers or discs as shown in Fig. 3, from:

Commanding Officer
Naval Weapons Station
Research & Development Division
Yorktown, Virginia
Attention: Mr. U. Cormier
Telephone: TUlip 7-2411, Ext. 521 or 332

Other explosives with equivalent characteristics may be employed. Stand-off distance shall be measured from the under side of the plate (from the face of the die) to the bottom surface of the charge. The charge should be carefully centered over the center of the die. The blasting cap shall be inserted in the topmost explosive wafer in tests where more than one wafer is used to make up the charge, in order to direct the explosion downward.

C. TESTING

1. Laboratory test specimens, as indicated below, shall be required from each group of samples submitted for test evaluation. The weldment from which the standard laboratory test specimens are taken shall be identified and a remaining portion or portions used for one or more of the conventional (not modified) bulge-test specimens. Longer weldments than shown in Fig. 1 can be fabricated by semiautomatic or

automatic processes such that two or more bulge test samples can be flame-cut from the weldment. For such weldments, however, the total length of each weld must be adequate to provide all of the laboratory test specimens indicated below:

(a) Transverse Tensile - Three transverse tensile specimens, prepared as specified in Fig. 2 of Standard MIL-STD-418, shall be taken from the end of one plate from each group of samples welded by the same method, materials and procedure - as shown in Fig. 1. These shall be tested at room temperature, in a standard tensile testing machine. The ultimate tensile strength, the yield strength (calculated at 0.2% offset), the per cent reduction in area and the per cent elongation shall be recorded - as well as the location of failure, as to whether it be in plate metal, weld metal, HAZ, or along the fusion line. Light chemical etching of the specimens prior to test to delineate these regions is permissible.

(b) Side Bend - Two side bend specimens, prepared as specified in Standard MIL-STD-418, shall be taken from the end of one plate from each group of samples welded by the same method, materials and procedure - as shown in Fig. 1. These shall be tested in accordance with the Standard.

(c) Charpy V - A minimum of 6 Standard Charpy V-notch specimens shall be taken from the end of one plate from each group as described above - as shown in Fig. 1. Charpy V specimens from weld metal shall be taken so that the top surface of the specimen is from a location nominally 1/8 inch or closer to the surface. All specimens shall be notched in a direction perpendicular to the plate surface. Light chemical etching of the specimens prior to notching is recommended in order to locate the notch wholly within the weld metal. Two specimens shall be tested at each temperature (room temperature, $0^{o}F.$, and $-60^{o}F$), and the energy absorption results recorded. When thick weldments are tested, additional specimens from the centerline area of the weld shall also be tested as stated above.

D. PERFORMANCE CRITERIA

1. Modified Crack-Starter Explosion Test - The two modified crack-starter weldments shall be tested prior to conducting the conventional bulge tests. These samples are used for quick screening purposes to determine if a continuation by bulge testing is warranted. The purpose is to develop an early crack which results in the

catastrophic propagation of a fracture if the weld, heat-affected zone, or fusion line have tendencies for low-energy propagation of this crack.

The specimens shall be refrigerated to a temperature sufficiently below the test temperature that heat gain during handling will not cause the test temperature to be exceeded. Test temperature shall be 0°F for all specimens. The refrigerated specimen shall be placed on the die with the crack-starter weld down. Using the stand-off and charge specified in Table I, one shot shall be fired. The fired specimen shall be carefully examined and the location, length and direction (preferably by a sketch or photograph) of all cracks recorded - together with a description of the fracture appearance, if visible. The development of fractures after one shot which extended into or through the hold-down regions of either of the modified test samples shall be indicative of high brittleness. It is suggested that this condition should be deemed to be below minimum acceptability levels. Materials or procedures being investigated which develop such a condition of weakness in modified crack-starter explosion test samples shall be rejected without continuing explosion tests of the remaining samples. In the absence of evidence of such a condition of weakness, the samples shall be returned to the cold box sufficiently long (about 1½ to 3 hours, depending on thickness) to equalize the test temperature throughout the sample. Using the same stand-off and charge, another shot shall be fired and the same information again recorded. The extension of fractures after two shots into or through one or both ends (hold-down regions) of the modified test samples causing complete separation of one or both weldments shall be considered to be below minimum acceptability levels, and conventional bulge testing of the remaining samples shall not be undertaken.

The development of short tears after the first shot, with only moderate extensions (to but not through the hold-down region) of these fractures by the second shot, shall be considered to be above minimum acceptability levels of performance in the modified crack-starter explosion test. Providing both crack-starter samples indicate performance above minimum acceptability levels, conventional bulge testing of the remaining samples shall be warranted.

2. Conventional Explosion Bulge Test - Only materials and processes which are demonstrated to perform above minimum acceptability levels of performance in the modified crack-starter test shall be further evaluated by conventional explosion bulge tests. Conventional bulge test procedures require the application of repeated explosive shots in order to delineate the critical regions of the weldment which participate in the initiation and propagation of fracture.

Acceptable performance, as defined below, must be exhibited with a minimum of 3 to 4 samples, or more conventional bulge test samples, as may be required by the BUSHIPS.

The specimen, refrigerated as indicated above for modified crack-starter explosion tests, shall be placed on the die with the side down being that on which the bead ends have been ground flush. Using the stand-off and charge specified in Table I, one shot shall be fired. The specimen shall be examined for visible signs of cracks. In the absence of cracks or separations, the reduction in thickness shall be measured and recorded, as indicated below. The specimen shall then be returned to the cold box and again refrigerated sufficiently long (usually about 1½ to 3 hours, depending upon thickness) to stabilize the temperature throughout the plate and maintain the test temperature. Using the same stand-off and charge, another shot shall be fired and the same information again recorded. The cycle - refrigeration, firing and examination - shall be repeated until a failure occurs or until the development, without visible failures, of a limiting bulge depth (bulge-limit) established prior to testing by the BUSHIPS as the requirement for the service application involved.

The development of a bulge-limit is a function of the relative flow strengths of the weld deposit, heat-affected zone and plate areas near the apex of the bulge. The maximum reduction in thickness of the plate at a point near the apex (approximately 1½ inch from the edge of the weld) shall be measured after each shot and recorded as a percentage of the original plate thickness. The per cent reduction in plate thickness after the first shot is roughly indicative of the weld-metal flow strengths. Overmatching welds (e.g. G260 on STS) developed 6 to 7% thickness reduction in the 1" STS plate on the first shot employing charge weights and stand-off distances shown in Table I as standard for HY-80 type weldments. For such weldments, full hemisphere bulge-limits in the absence of failures were generally developed in one-inch thick weldments after three shots and approximately 16 per cent thickness reduction of plate. The per cent thickness reduction of plate shall not of itself constitute a definition of "bulge-limit", because this parameter will vary with the geometry of the die, the flow strengths of various areas in the weldment and the thickness of the sample being tested. However, the development of less than three per cent thickness reduction of plate as a result of the first shot on any given sample shall be considered inadequate and the charge weights and stand-off distances shown in Table I shall be modified for conventional explosion bulge tests of the remaining samples of a given group. Stand-off distances less than 15 inches, shall not be employed for any test.

Testing of any given sample shall be discontinued upon the attainment of a prescribed bulge-limit with no visible evidence of fractures. In the event a visible failure is developed in a sample, the fracture surface shall be examined, if possible and the mode of failure with a complete description as to number, length and path of failures shall be recorded - together with the percentage reduction in specimen thickness developed on the shot preceding the failure shot. The development of failure indications (surface weld tears, longitudinal toe cracks, etc.) shall be noted as above and the sample shall be returned to the cold box sufficiently long to equalize the test temperature throughout the sample. Using the same stand-off and charge, another shot shall be fired. Thickness reduction measurements shall not be taken.

The development of first visible fractures which consist of transverse (square) weld-cracks which penetrate the weld thickness, or longitudinal fractures which extend into or through either end (hold-down region) shall be considered below the minimum acceptable level of performance in the conventional bulge test. This condition shall be cause for rejection and a "next" shot shall not be fired. For samples given a next shot, extensive propagation of first visible failure indications into or through either end (hold-down regions) of the sample shall also be considered below the minimum acceptable levels of performance in the conventional bulge test.

The complete explosion bulge testing sequence, and an evaluation technique based upon the suggested minimum acceptability standard are illustrated in Fig. 4. For various service categories which are designated by the BUSHIPS to require more than the minimum acceptable fracture toughness, the same procedures illustrated in Fig. 4 may be utilized with a more restrictive acceptability level. Fig. 5 provides a suggested frame of reference for the choice of acceptability limits which may be assigned to various service categories. It is suggested that the C-ring limit of propagation indicated in Fig. 5 should be considered the minimum acceptable level because fracture propagation outside of the C-ring limit implies high brittleness. The choice of materials which restrict propagation to A-ring or B-ring limits should be based upon BUSHIPS determined minimum levels of fracture propagation applicable to specific service requirements.

FIGURE CAPTIONS

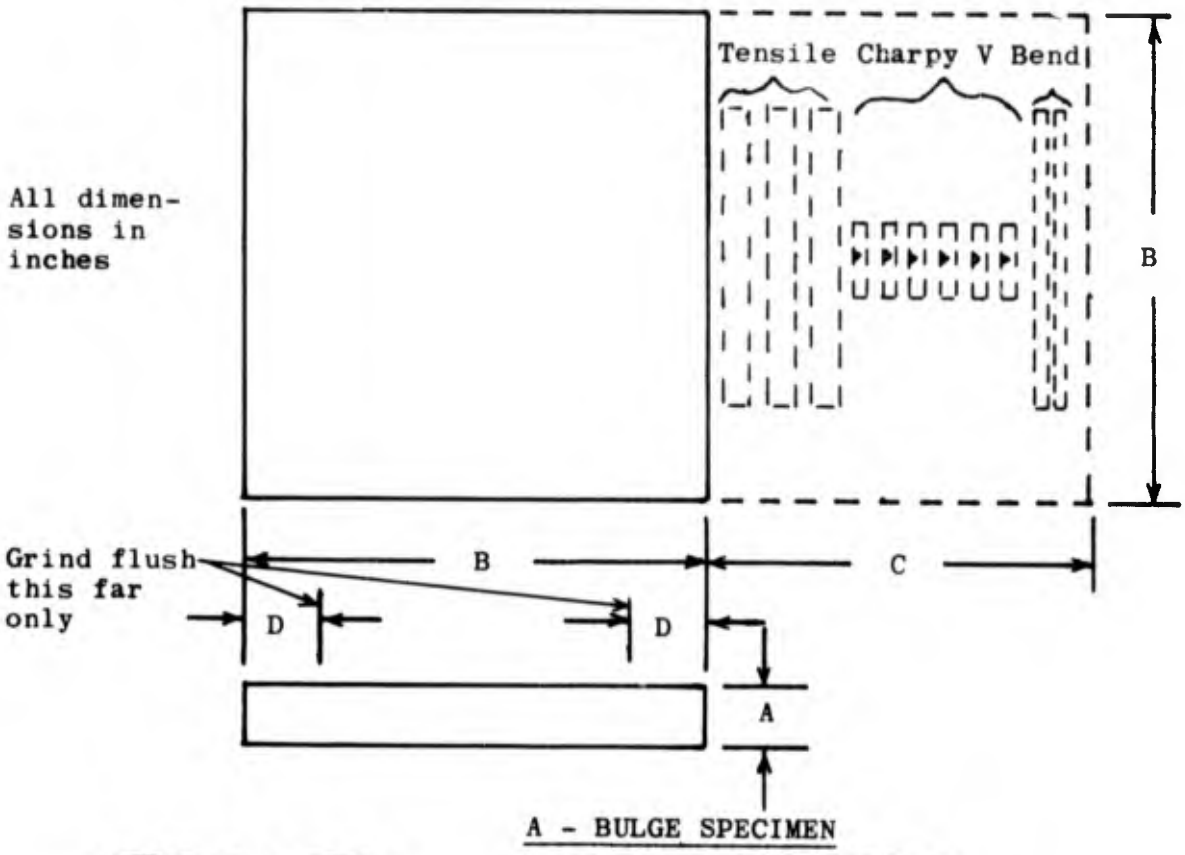
Fig. 1 - Explosion Test Specimens

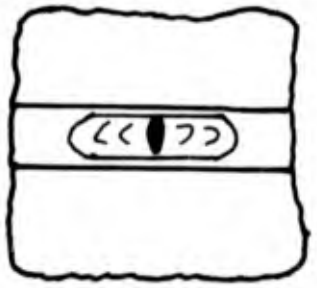
Fig. 2 - Standard Die

Fig. 3 - Cast Pentolite Charge

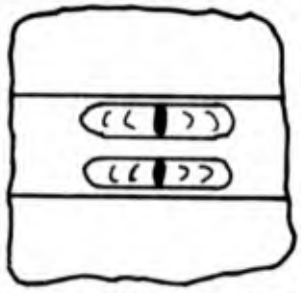
Fig. 4 - Explosion Test Evaluation Techniques

Fig. 5 - Frame of reference depicting possible acceptability limits which may be assigned to various service categories.





1 - 1½" Plates

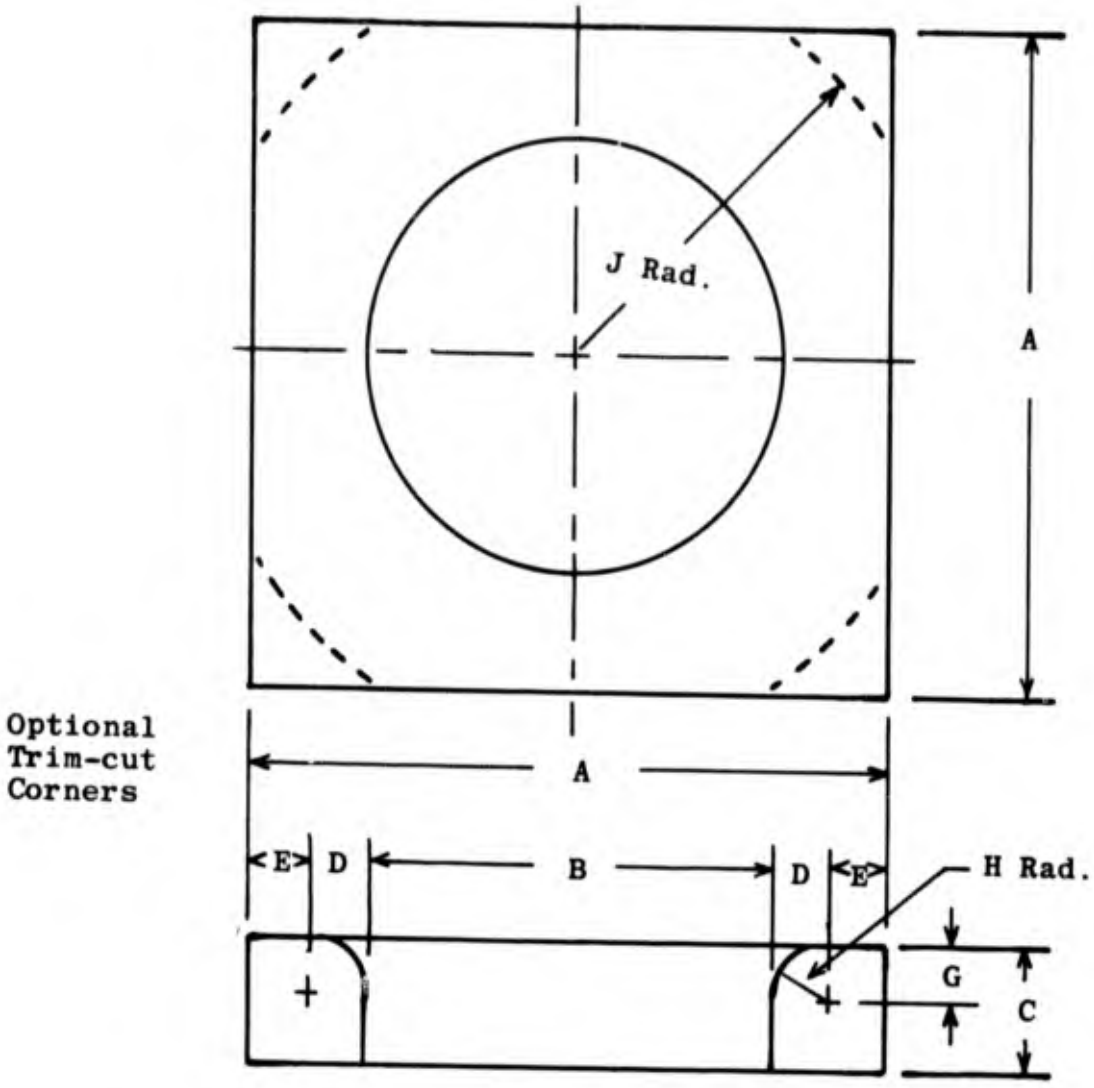


1½" and Thicker Plates

B - CRACK-STARTER

	A	B	C	D
1	thru 1¼	20	15	5
1-3/4	thru 2½	30	13	7

Figure 1 - Explosion Test Specimens



All Dimensions in Inches

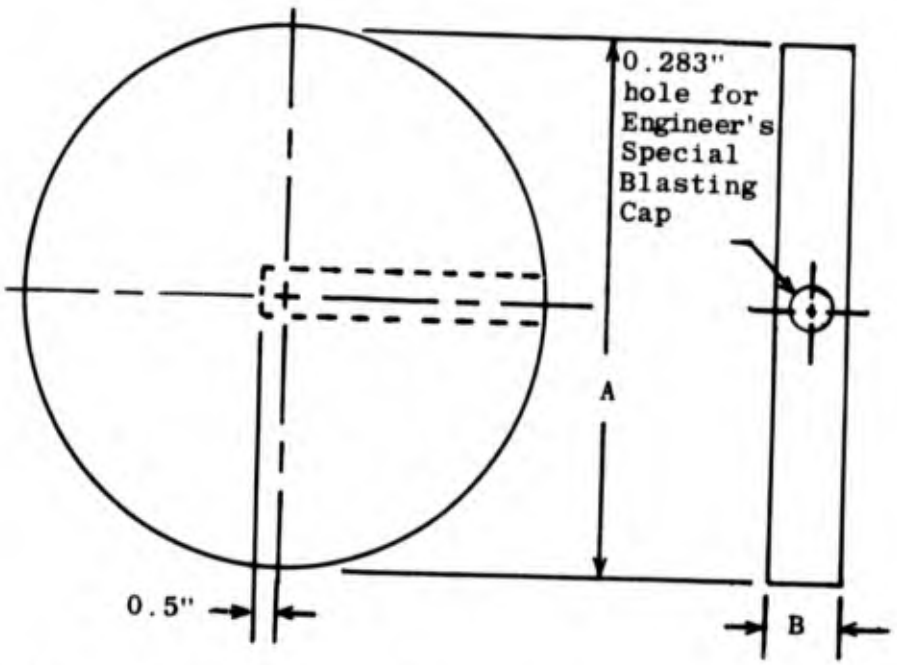
	A	B	C	D	E	G	H	J
Type I	20	12	3	1.5	2.5	2	2	-
Type II	30	18	4	3	3	3	3	17

Figure 2 - Standard Die

Table I - Die, Charge and Stand-off

(All Dimensions in Inches; All Weights in Pounds)

Plate Thickness	Dimensions	Die	Weight Charge	Stand-off Dist.
1	20x20	I	7	15
1-1/4	20x20	I	12	19
1-3/4	30x30	II	24	17
2	30x30	II	24	15
2-1/2	30x30	II	36 - 40	15

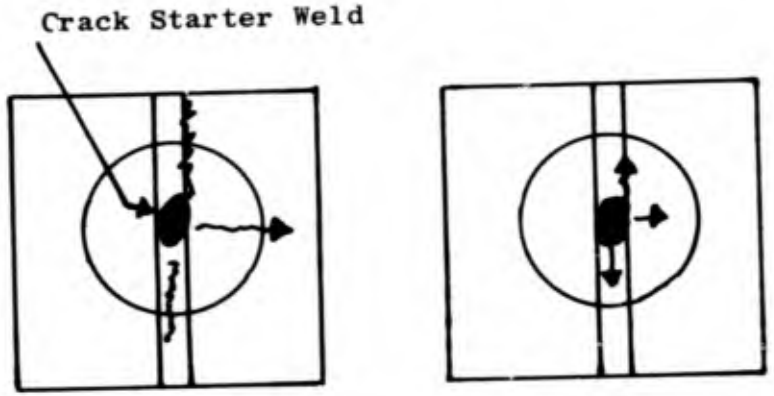


Charge Weight	A	B
1 #	5	7/8
4 #	10	1
7 #	10	1-1/2

Individual Charges are Stacked to Produce Total Charge.

Figure 3 - Cast Pentolite Charge

EXAMPLE OF EVALUATION BASED ON SUGGESTED MINIMUM ACCEPTABILITY STANDARDS

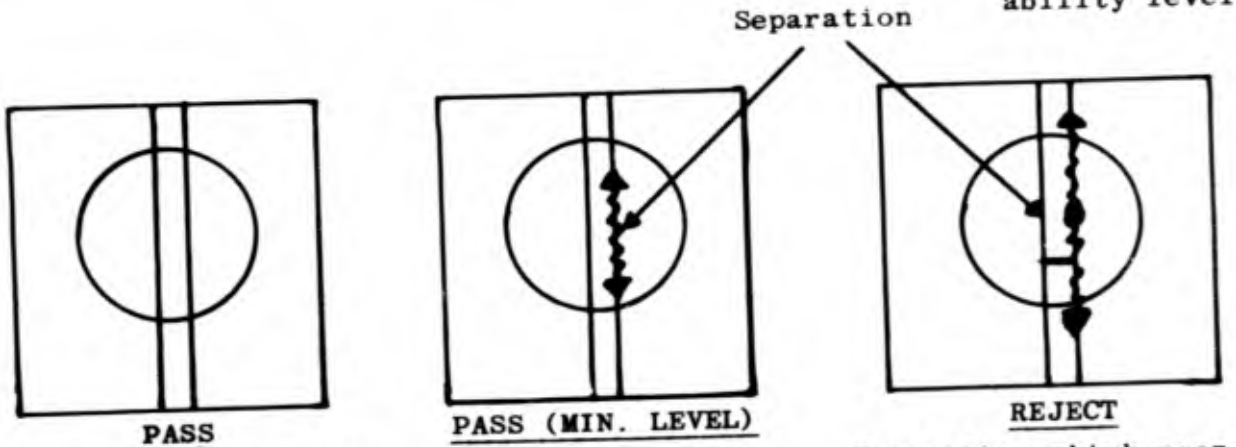


REJECT

PASS
(MINIMUM LEVEL)

(A) Preliminary Screening For The Presence Of Low Energy Propagation Paths.

(1) Apply one shot to develop cracks or tears.
(2) Apply second shot to test for resistance to propagation.
(3) Reject if either plate shows fractures extending outside of bulge region.
(4) Continue with conventional explosion bulge test samples if both modified crack starter samples pass minimum acceptability level.



PASS

3 or more attain bulge-limit without failure.

PASS (MIN. LEVEL)

Separation does not propagate out of bulge region as a through crack on next shot.

REJECT

Separation which propagates outside bulge region as through crack,
or
transverse weld crack completely through weld thickness.

(B) Final Evaluation For HAZ Performance.

(1) All plates, 3 or more, as required, must pass.

Figure 4 - Explosion Test Evaluation Techniques

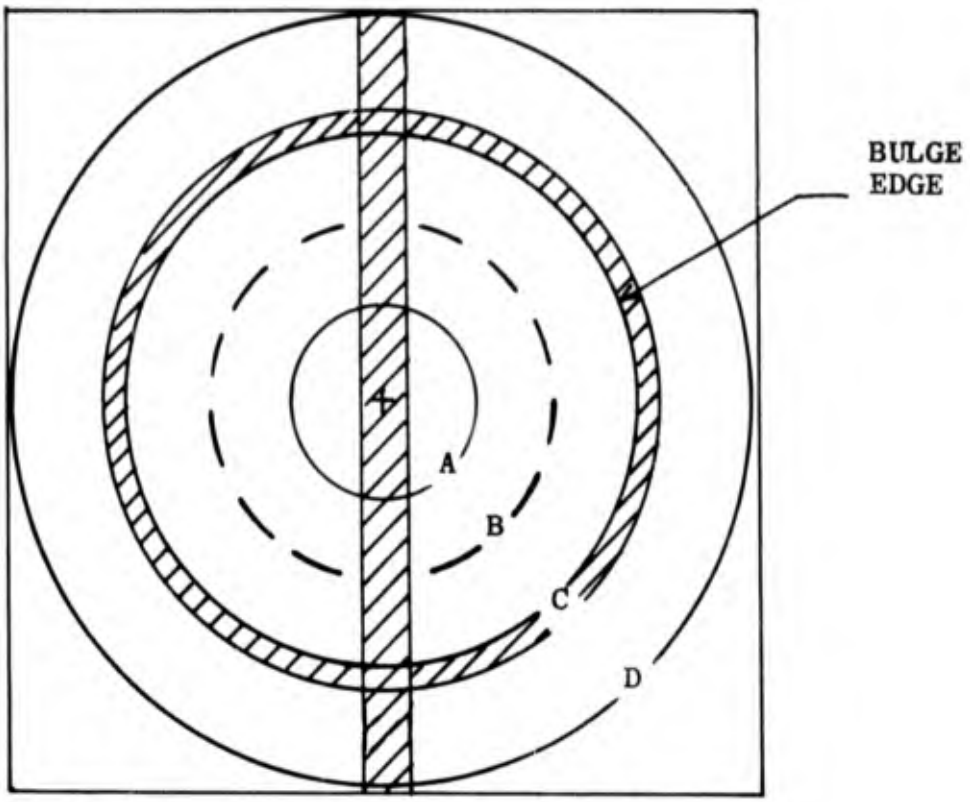


Figure 5 - Frame of reference depicting possible acceptability limits which may be assigned to various service categories.